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BASIC PROBLEMS OF POWDER METALLURGY IN THE LIGHT OF THE DECISIONS OF THE 19th CONGRESS OF THE COMMUNIST PARTY OF THE SOVIET UNION

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APPENDIX A
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# THE BASIC PROBLEMS OF POWDER METALLURGY IN THE LIGHT OF THE DECISIONS OF THE 19th CONGRESS OF THE COMMUNIST PARTY OF THE SOVIET UNION

By

V.S.Rakovski

[redacted]



## I. General Remarks

A conference on the problems of powder metallurgy took place in Kiev in September 1949 under the auspices of the Institute of Ferrous Metallurgy of the Academy of Sciences of Ukraine, together with the local Kiev section.

Considerable changes have occurred during the last four years in the field of powder metallurgy: It has passed the laboratory stage and is more and more used in industry. Also, while in 1949 the advantages of powder metallurgy were not well known, now many branches of the industry show more confidence and interest in powder metallurgy. A number of new powder metallurgy processes have been assimilated by various organizations during the last four years, having successfully passed the laboratory and production tests. Among them we note leaded bronze bearings; large size friction brake discs for operation in oil; friction materials having a high friction coefficient and showing little wear at high operating temperatures; magnetic materials having high magnetic properties, obtained by roll-pressing (lamination) of powders; special refractory products for work at high temperature; large size iron-base bearings replacing Babbitt; special alloys showing high strength and stability at high temperatures; and many other manufactured products.

Extensive contributions to the theory of powder metallurgy, especially sintering, have been made in the last years by Soviet scientists. The work of Frenkel, Balshin, Ivensen, Pines, Fedorchenko, Nazarov, Lichtman, and a number of others, has considerably advanced our knowledge in the theory of powder metallurgy - in the basic understanding of its processes. The field of powder metallurgy still has many problems which require an answer. During this 19th Congress of the Communist Party of the USSR, eighty-five organizations were represented, and decisions for further development of powder metallurgy will follow the findings of this 19th Congress. The following are the main problems which require a solution in the field of powder metallurgy.

II. Scientific Problems in Powder Metallurgy

The 19th Congress has stressed the necessity of a more efficient use of natural resources of our country, economy of materials, especially metals. Powder metallurgy could accomplish this. Further progress in many technical branches cannot be achieved without powder metallurgy, e.g., problems in radioactive tracers, creation of new refractory alloys, new magnets with high magnetic properties. To accomplish this, it is necessary to widen further the scientific foundations of powder metallurgy. Although Soviet scientists have made considerable contributions, they are insufficient for further advances, and the present trend may slow down future progress.

It is wellknown that the basic operations in powder metallurgy are pressing and sintering. Pressing has been subjected to a rather detailed study by a number of Soviet scientists, especially Balshin, who has given answers to many theoretical aspects of the problem. Outstanding work has been performed by Frenkel, Pines, Ivensen and Fedorchenko.

We must note, to the credit of these scientists, that they have tried to explain quantitatively the process of sintering, by using mathematical expressions, and have tried to streamline the theory of this process. However, even the best of these theories are often somewhat one-sided; they do not take fully into account the real properties of existing materials; their presentation is often too abstract; and they show too many blank spots on some of the aspects of the problem. Let us cover this field in more detail:

The process of pressing has been fairly well studied in the form of uni-directional, or at best two-directional, pressing. However, it is well known that such processes do not insure a uniform pressing of the powder in the manufacture of products of complicated shapes, such as gas turbine vanes. A solution might be found in hydrostatic pressing. Such a process certainly has a large future, but its theory has almost not been worked out at all. No research has been done on subjects such as "the influence of technological factors on the geometric shape of the final product", on the degree of uniformity of pressing, on the behavior of individual powder particles. The problem of multi-directional pressing under high pressure is also among the "blank spots" of the theory of pressing.

The work of Bridgman, White, and of Soviet scientists Ratner, Oding, Korneev, and others, has established that multi-directional pressing of compact metals and alloys under high pressure, may considerably change the nature of the material, and make plastic materials out of brittle ones. This problem has not been studied at all in its application to the sintered products, although it presents a considerable interest in the production of alloys of the metal ceramic type having a high strength at elevated temperature, obtained from refractory metals and their carbides.

The theory of the so-called "conventional" pressing also has its blank spots. Almost no study has been done on the behavior during pressing of strongly oxidized powders, or of powders whose particles are covered by strongly adherent oxides, such as aluminum ($Al_2O_3$). However, the pressing of mixtures consisting of metallic and ceramic particles presents a considerable interest in practice, especially for refractory alloys. There is no doubt that inner stresses occur in the pressed material, but nothing has been worked out in the field of methods of measuring these stresses, or their theory.

The theory of sintering has probably even more defects. The main trouble lies in the fact that up to now there has been no single theory of sintering which completely covers all aspects of this important process. Each scientist studies miscellaneous separate aspects of sintering, and there is as yet no general theory. Individual theories have blanks and defects, and this is true even of the most thorough and complete theories of Soviet scientists.

Further, it must be noted that in his mathematical calculations Balshin often tolerates replacing some physical quantities by others, and assumes that this does not influence the final result. We must, of course, take exception to this conclusion. Balshin believes that the mechanism of densification during sintering is accompanied by a simultaneous inverse process of "rarefaction". While such an interpretation is rather dialectical, it is difficult to understand and has no practical application. Densification leads to a reduction in volume; rarefaction leads to volume growth. Both processes cancel each other. The existence of growth during sintering is explained by the presence of oxides by release of stresses, elasticity phenomena, etc.

Balshin feels that there is no basic difference between the mechanism of pressing and the mechanism of sintering, and that whatever differences exist are only quantitative. We cannot agree with this. Finally, we must note than an overwhelming majority of Balshin's theoretical results are not confirmed by experience, and are rather abstract in character.

The theory of Fedorchenko is based on the idea that the active force in the mechanism of sintering is an excess in the surface energy of the particles. This idea shows like a red thread throughout all Fedorchenko's theory.

Of course, surface phenomena have a considerable influence in the mechanism of sintering. However, Fedorchenko makes the mistake of overestimating the importance of surface diffusion and underestimating that of volume diffusion. It must be further noted that Fedorchenko rejects the idea of viscous flow without a sufficient justification for this opinion, and feels that recrystallization during sintering has a different character from the one occurring during deformation. Fedorchenko's statement that during sintering we have transport of atoms from the contact areas to the voids is not sufficiently founded.

The theory of sintering presented by Frenkel, which has been widely accepted in the USSR as well as abroad, admits that the only factor which slows down the sintering process is the presence of gases in closed pores. This cannot be accepted as correct, as this slowing down - and quite a noticeable one - is apparent even in the first stage of the process when the pores are still open. Frenkel's theory does not take into account the dispersion of the powder, while this factor certainly has a considerable influence. Moreover, Frenkel assumes that viscous flow is exactly the same in liquids and in solids, while, in fact, their mechanism is quite different. For sintering to occur in solid phase through viscous flow, the mass being sintered must be subject to stresses important enough for the flow to take place. Calculations show that this mechanism is possible for particles not exceeding 3 microns. Finally, it must be noted that Frenkel admits the existence of only spherical pores, while actually their shape is very varied and as a rule is not spherical.

The theory of Balshin takes into consideration such real factors as recrystallization, diffusion, state of dispersion of the powders, particle shape, etc. However, Balshin's theory also has a number of weak points, as follows:

The mathematical formulas suggested by Balshin predict a rather sudden decrease of the speed of densification, which has never been noted in practice. The explanation of the mechanism of densification of a porous body, as resulting from surface migration of atoms, is somewhat one-sided. Volume diffusion and not surface diffusion has a considerable - and possibly predominant - influence. In real metal-ceramic bodies, the state of energy of the atoms of the inner surface of the porous body is extremely heterogeneous even within the boundaries of individual particles. It is therefore difficult to accept the existence of a definite direction for the movement of atoms to an appreciable distance, in a body where the condition of these atoms is so diversified.

Finally, we must note the theory of Ivensen, which covers mainly the kinetics of densification during sintering. Ivensen's theory is well "streamlined". His mathematical equations have been quite well confirmed by experimental results. The premises that he accepts are real. However, Ivensen's theory has its drawback in the fact that Ivensen has limited his work to the study of low densities, and his theory is somewhat remote from the real conditions encountered in metal-ceramic material.

To supplement all this, we must note that modern methods of fesearch are as yet very little used in theoretical work on powder metallurgy. We refer to the electron microscope method, the radioactive isotopes, the phase analysis - all of which are widely used in many branches of general metallurgy. Little work has been done on a detailed study of various physical properties of metal powders,on integration of metal-ceramic products in the industry, and on a more thorough development of the theory.

From this brief survey of the defects of the theory of powder metallurgy, we gather the main problems in this field, the most important being as follows:

1) To work out the theory of volume pressing, establishing the influence of the main technical factors on the geometrical similitude of the final product, on the degree of uniformity in pressing, and on the behavior of the particles of the powder being pressed.

2) To work out the theory of hydrostatic pressing of the sintered products under high pressures; to determine a physical explanation for the changes in plasticity of the materials under the influence of high pressures.

3) To work out a complete theory of other new methods of pressing, starting with such as vibratory compacting, hot pressing, etc.

4) To determine differences in the nature and kinetics of sintering of blends of separate components, and of alloys of the same components in the case of solid solutions, chemical combinations and mechanical mixtures.

5) To study the influence of ultrasonics on the mechanism and kinetics of sintering. It is known that the application of ultrasonics has a noticeable effect on the mechanism of crystallization; an alloy will crystallize in the shape of micro-crystals, and its properties are considerably improved. Under the influence of ultrasonics, the mechanism of sintering of particles of completely different materials is considerably activated. Some separate experiments of sintering under the influence of ultrasonics have shown that the process is considerably activated. However, the theory of this question has not been developed at all, especially in its application to subjects of such practical importance as mixtures of metals and oxides.

6) To study the mechanism of diffusion during sintering, with the help of radioactive isotopes and spectroscopy, and to determine the quantitative laws applying to sintering of mechanical blends, solid solutions, and chemical combinations. In many works, considerable importance is given to the processes

of diffusion, but this is covered in an abstract manner, and is not sufficiently confirmed experimentally.

7) To eliminate defects and deficiencies existing in the present theories on sintering of Frenkel, Ivensen, Balshin, Fedorchenko, and others. Especially, is it well worth while to widen and supplement Ivensen's theory on the kinetics of densification, which has been worked out for small pressures and low densities, and should also now cover the practically more important field of high densities.

In their work, Balshin and Fedorchenko pay considerable attention to the problem of recrystallization during sintering, but the quantitative laws of this phenomenon have almost not been studied. It is necessary to establish recrystallization diagrams referred to "grain size - pressure during pressing - sintering temperature" for one-component systems, solid solutions, mechanical blends, and chemical combinations. Finally, it is imperative that the theory of sintering be considerably widened and the separate theories progressively integrated into one single theory of sintering, explaining all the separately studied problems.

Our science should become the first one in the world!

## III. Technological Problems in Powder Metallurgy

The 19th Congress of the Communist Party of USSR confirmed the directives concerning the development of our industry for the years 1951-55, which foresee an important technical development of all branches of our economy. The guiding ideas in the development of our technology are automatization, mechanization, and intensification of manufacturing processes. These directives call for the creation of a number of new instruments, machines, new high quality materials, especially refractory alloys, and others. In this technical development, powder metallurgy will play an important role. For instance, a wide development of automatization is not possible without the use of the most complicated electronic instruments, photoelectric cells, miscellaneous magnetic apparatus, and of a number of other apparatuses and instruments in which the products of powder metallurgy find a wide application: parts made of refractory and rare metals, special magnets, and others.

As a result, we have the problem of a wide application of these products to industry, and of the creation of a central plant for their manufacture. In addition, there are a number of more specific problems. As you know, the metal-ceramic magnetic products already find a wide application. However, new problems create new needs. New developments in technology require the use of magnetic materials having very strong magnetic properties. Powder metallurgy helps to solve this problem. The work done lately in the USSR and abroad has shown that rolling sharply increases the magnetic permeability and other magnetic properties of magnetic materials. Professor Aksenov has developed the technology of manufacture of a strip directly from powders by rolling. The application of this method to magnetic powders may lead to the creation of new materials with very high magnetic properties. This method should be widely applied in industry.

An important development of the manufacture of magnetic materials requires the development of an iron powder manufacturing process by electrolysis. At the present time this method has not been sufficiently perfected, and this defect should be promptly corrected.

The second guiding idea outlined by the 19th Congress of our party foresees an important development of mechanization. This means the development and mass production of powerful shovels, bulldozers, drills, transporters, and a number of other machines. Powder metallurgy products find their application in an overwhelming majority of these machines. For instance, the work of

VIAM* and TSNIITMASH* has resulted in the creation of high quality friction materials which withstood tests satisfactorily.

The coal industry has been successful in developing cheap iron-graphite bearings for conveyors, instead of the expensive and poor quality ball- and roller-bearings. The coal industry of the USSR now has an important plant manufacturing porous bearings. One of the plants of the Ministry of Metallurgical Industry has developed the production of high quality iron powder. However, its output is quite insufficient, and the development of metal-ceramic products is not satisfactory.

The importance of the integration of powder metallurgy products in industry is stressed by the fact that the production of porous bearings from iron powder at the Laptev plant of the Ministry of Coal Industry has permitted within a short time savings of over 15 million rubles to the people's economy.

It is imperative to speed up the creation of important central plants for the manufacture of metal-ceramic products, and at the same time increase the production of already available iron powder.

The selection of a production method on an industrial scale for iron powder is very important. At the present time the USSR has available many good methods developed in industries and research centers. The following methods should be noted:

NIIT-Ferrous Metallurgy * has developed a method of reduction of steel mill scale by hydrogen in a rotating furnace.

The Laboratory of Special Alloys of the Academy of Science of the Ukrainian SSR has developed a method of scale reduction by natural Dachau gas.

*Transliterated initials standing for name of a government agency (not known to the translator)

The Sulinsk plant has developed the reduction of scale by solid carbon.

Engineer Malkin of the Stalin Steel Institute has developed a very cheap and simple method of obtaining iron powder from Krivoi Rog ore by reducing it with soot.

TSNIITMASH* has developed the production of iron powder by atomization of liquid cast iron.

There are also many other methods. They all permit to obtain a high quality product. We must decide in the near future which method should be selected for the centralized production of iron powder, and create unified technical standards or a AH CYYP* for iron powder. The development of the methods of the Sulinsk plant and of the AS UkSSR appears expedient as these methods result in obtaining the best quality product at a low cost.

The third guiding idea in technical development is the "intensification of the processes", in a broad sense of these words. The intensification of the processes (or obtaining materials with better properties) is apparent in all the branches of our technology. Let us mention some examples:

In aviation: The creation of high speed planes, mostly jet propelled.

In power: Creation of high pressure gas turbines.

In naval construction: Creation of high speed ships.

In metalworking: Machining at high speeds.

An answer to these problems can be found only by using special materials: metal-ceramic hard alloys, highly refractory alloys, highly wear-resistant friction materials, for instance for planes which even now have landing speeds of 400 to 500 kilometers/hr, and in the brakes of which temperatures up to 1200°C are attained when brakes are applied. Such materials can be created only

* See note on preceding page

by powder metallurgy; thus posing new technical problems in the creation of these materials, i.e., refractory alloys, friction materials, and metal working alloys.

Attention must be called particularly to the following problems:

At the present time, friction materials are made by pressing a metal-ceramic layer on to a steel base. For large size friction parts this means using powerful presses, which is not always possible. Preliminary tests made in the USSR have shown that the metal-ceramic layer can be put on by means of high frequency currents. It would be advisable to thoroughly develop and apply this method.

The creation of high quality refractory alloys of the metal-ceramic type requires a thorough study of their nature and properties. We must note that thi work has to be extended and intensified.

To sum up, the technical problems of powder metallurgy may be summed up as follows: Set up the production of iron powders, magnets, contacts, on a large industrial scale; create new types of refractory alloys; develop on an industrial scale the method of powder rolling, the method of applying metal-ceramic layers by high frequency currents, and the method of volume pressing.

The 19th Congress of the Communist Party of the USSR has stressed the need of elimination of waste in the use of materials, the necessity of their more efficient use, especially in the case ofmetals. Powder metallurgy is one of the most efficient means for solving this problem. The wide application of powder metallurgy permits considerable savings in the use of metals by considerably decreasing machining and by permitting the use of by-products for the manufactu of quality parts.

Let us mention a few examples. Work done during the last few years in the automobile industry (AH CYYP) has led to the successful development of bearings with a layer of lead bronze which is in no way inferior to cast bronze. In this process, powder metallurgy affords a reduction in metal consumption to one-eighth its former figure.

The same branch has also developed the manufacture by powder metallurgy of high quality parts from the steel powder obtained as a by-product in the manufacture of ball bearings, instead of making these parts by machining from rolled steel which must be subjected to further treatment.

Powder metallurgy permits the manufacture of watch-mechanism parts from shavings. Successful work in this field is being done by AH CYYP and the Mechanic Institute of Moscow. The assimilation of this method will considerably decrease machining and permit a large saving in the amount of metal used.

The process of electroforming, developed and suggested by Vassiliev, is now well known. This process permits to obtain high quality ball bearings out of Al-Fe alloys, as well as a number of other products and materials. A wide application of this method to industry permits large savings in the use of metal.

Powdery metal bearing by-products are successfully used by application of powder metallurgy methods for the manufacture of high quality welding rods.

The main problem in this field is a fast completion of the work already started, and a fast application of the results to industry. The most important problems are the development of metal-ceramic titanium-bronze and that of electroforming.

## IV. Organization Problems of Powder Metallurgy

The measures taken by the party and the government for the reorganization of industry according to the decisions of the 19th Congress of the Communist Party of USSR have laid a favorable foundation for a further successful development of powder metallurgy and the organization of large central plants for the manufacture of metallic powders and metal-ceramic products.

We have a problem in the creation of a number of central manufacturing units in the frame of the enlarged ministries, each with a given direction in its activity. In the Ministry of Machine Construction, it is advisable to create a central producing plant for metal-ceramic products corresponding to the standard part nomenclature of this ministry. Likewise, the Ministry of Transpor and Heavy Machinery should have a centralized production of mostly friction parts, and the Ministry of Electrical Industry and Power Stations should develop a centralized production of contacts and miscellaneous magnets. We must speed up the development of a centralized production of iron powder on a sufficiently large scale under the control of the Ministry of Metallurgy.

At the same time, the different ministries must develop large powder metallurgy laboratories which could direct further development of this branch in each ministry.

The second problem relates to technical education and preparation of specialists. It is inadmissible to find that the students of special schools for machine construction are generally unaware of the modern methods of powder metallurgy, which, in fact, is one of the methods used for machine construction. It is imperative that the curriculum of metal technology include courses on powder metallurgy.

The third organization problem relates to the systematic publication of technical literature about the problems of powder metallurgy.

Finally, it is essential to coordinate the scientific and technical work of all organizations concerned with powder metallurgy problems.

A special committee on powder metallurgy should be created at the

Presidium of the Academy of Sciences of USSR, having sufficient powers for the control of progress on the most important powder metallurgical problems, for organization of scientific discussions, for publication of textbooks on powder metallurgy, for organizing contests, etc. This committee should include representatives from industrial plants and scientific research institutes. It is also advisable to create a committee on powder metallurgy within BCNITO and BNITOMASH, instead of the present multiple sections existing with different scientific, engineering and technical groups.

## APPENDIX A

**POWDER METALLURGY**
Kiev, 1955 (194 pages)

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|---|---|
| 1. Rakovski, V.S. | Basic problems of powder metallurgy in the light of the decisions of the 19th CPSU Congress |
| 2. Meerson, G.A. | The current status of the theory of the basic processes of powder metallurgy |
| 3. Fedorchenko, I.M. | Some rules of the process of sintering conglomerates from metal powders |
| 4. Pines, B.Ya. | Sintering, creep, relaxation, recrystallization and other phenomena dependent upon self diffusion in crystalline bodies. |
| 5. Ivensen, V.A. | Theory of sintering |
| 6. Ter-Grigor'yan, E.L., et al | On the sintering of metal powders at low temperatures |
| 7. (same authors) | A spectral method of determining the coefficients of diffusion of chromium in iron |
| 8. Kornilov, I.I. | Investigation of the structural diagrams of high melting metals and metal compounds by powder metallurgical methods |
| 9. Frantsevich, I.N. | Mild, magnetic metallo-ceramic alloys |
| 10. Natanson, E.M. | Organosols of metals and new methods of obtaining them. |

APPENDIX B

POWDER METALLURGY
Jaroslavl, 1956
(322 pages)

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I. STATE OF POWDER METALLURGY AND MAIN PROBLEMS CONNECTED WITH ITS DEVELOPMENT

1. Theoretical questions
2. Oonsiderations on a few questions on the theory of sintering
3. Study of the process of sintering of some metal powders
4. Study of the diffusion process during sintering in the presence of radioactive isotopes
5. On the influence of copper in iron-graphite
6. Study of a few laws of diffusion hardening in iron-copper-carbon cermets
7. On the structure of iron-copper-carbon cermets
8. Some features of the sintering of multicomponent systems
9. Structure formation in iron-graphite compounds during sintering
10. Strength of hard cermets of carbide, tungsten and cobalt
11. Technology of manufacture of iron powder by reduction of scale by natural converter gas

II. TECHNOLOGICAL QUESTIONS

12. Technology of manufacture and quality of iron powder of the Sulinsky Metallurgical Plant
13. Properties of iron powders prepared by different methods
14. Application of converter natural gas as protective and reducing atmospheres in the manufacture of cermets
15. Hydrostatic pressing of metal powders
16. On the calculation of dies used for the pressing of metal powders
17. Sintering of samples of metal powders in vacuum induction furnace
18. Mechanical properties and wear resistance of products made of iron powder coming from the plant of the Ministry of Ferrous Metallurgy
19. Friction cermets on an iron base
20. Large size bearings for railroad cars
21. Manufacture of cermet inserts
22. Soft magnetic cermets
23. Metal-ceramic permanent magnets
24. Manufacture of anti-friction metal-ceramic products
25. State of assimilation and development perspectives on powder metallurgy plants